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ASPECTS OF POLLEN COLLECTION BY HONEYBEES

by



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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF ENTOMOLOGY

EDMONTON, ALBERTA

MAY, 1967

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Aspects of Pollen Collection by Honeybees" submitted by Margaret Ann Skirving in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The quantity of pollen collected by bees, the range of plant species foraged for pollen, the relationship of pollen pellet to pollen grain size, competition from other insects for pollen, and the question of pollen preferences have been considered.

While day to day variation in the amounts of pollen collected by the colonies could be explained in terms of the weather, the condition of the colony appeared to be the most important factor governing the amount of pollen collected on a seasonal basis.

I consider their abundance and closeness to the hive as main factors governing the range of plants foraged for pollen by bees.

Concerning the weight of pollen pellets and its relationship to plant species in general the larger the pollen grain the larger the pollen pellet carried by the bee. However the sculpturing of the pollen grain, its shape, and the abundance of the pollen per flower affected the size of the load.

In the study area with abundant supplies of pollen, competition for pollen by other insects was considered unimportant.

Experiments in the laboratory exposing bees to only the odour of certain pollens did not show that bees respond more strongly to some pollens than others.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. B. Hocking, chairman of my committee, who has guided this study, for his helpful suggestions and aid in the preparation of this manuscript.

My special thanks are extended to the National Research Council of Canada who, through a grant, supported this study.

I would like to thank Dr. L. Kennedy for the loan of her pollen reference slide collection, and Dr. P. Pankiw who sent me pollen from Beaverlodge.

I thank Dr. K. Lesins (Department of Genetics, University of Alberta, Edmonton) and Dr. D.A. Craig (Department of Entomology, University of Alberta, Edmonton), members of my committee.

I would like to thank Miss Diana Pilcher for help during the laboratory work, and Dr. G. Pritchard for advice on statistical methods.

I thank Mr. J. Edmunds and Mr. R. Topping of the Alberta Department of Agriculture for their assistance, and all my friends who helped me with taking care of the bees, especially Mr. W.J. Awram and Mr. P.G. Kevan.

I wish to extend special thanks to Mr. David Larsen and Miss Dariel Sparling who helped me during the preparation of this manuscript.

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LITERATURE REVIEW

The pollen of flowering plants plays an important role in the life of the bee. It is the main source of the protein (Auclair and Jamieson 1948, Weaver and Kuiken 1951), fat (Hugel 1962), vitamins (Schwarz and Kock 1954, Bukatsch and Wildner 1956) and minerals (Lubliner-Mianowska 1956) that a colony needs to maintain itself (Parker 1926, Betts 1928, Eckert 1942, Haydak and Tanquary 1943, Vivino and Palmers 1944, Rashad and Parker 1958).

The chemical composition and nutritional value of pollens vary between plant species (Lunden 1954). The pollen pellets differ in colour, size, and arrangement in the corbiculae of the bee according to the species of plant, its method of pollen presentation and the weather at the time of presentation (Hodges 1952, Maurizio 1954). The pollen in a pellet usually comes from a single plant species, but may come from two or more (Betts 1920, Parker 1926, Hodges 1952). The pollen within a pellet may be segregated by species or it may be mingled. Of 568 loads examined by Betts (1935), 12 were mingled and 5 segregated, the remainder contained pollen from single plant species.

The weights of pollen loads carried by bees differ according to the source (Park 1923)

Prior to 1934 pollen loads for examination were collected by capturing bees at the entrance to the hive and removing the loads from the corbiculae by hand. Todd and Bishop (1940) were

the first workers to use a pollen trap extensively. Their traps were based on a design by Eckert and later improved by Farrar (1934). Modifications to this trap have been made by Eckert (1942), Killion (1945), Synge (1947), Rashad (1957), Nye (1959), Smith and Adie (1963).

All pollen traps consist essentially of a system of meshes through which returning bees must pass to enter the hive. The meshes are such that unencumbered bees pass through with ease but bees carrying pollen loads have difficulty; this results in up to two thirds of the total pollen loads brought into the hive being knocked from the corbiculae into a collecting tray (Smith and Adie 1963).

The amounts of pollen collected by colonies of bees are governed by factors which affect the plants on which the bees forage and the flight activities of the bees. The most important of these factors is the weather, followed by the availability of pollen and the condition of the colony as a whole (Lundie 1925, Hutson 1926, Phillips 1930, Filmer 1932, Brittain 1933, and Todd and Bishop 1940).

A bee usually collects pollen over a small well defined area in which she may visit flowers of only one species. This phenomenon of flower constancy has been known since the time of Aristotle (Thompson 1910). However it was noticed by many workers that colonies collect pollens of plant species in varying proportions.

In 1947 Synge attempted to explain these variations by suggesting that colonies may favour particular species of pollen. She offered selected colonies of bees a choice of pollens. Pollen loads from different plant species were crushed and put into glass containers fixed to a wooden block in a Latin square design. The results showed that bees chose certain pollens over others. The pollens used in the experiments had been collected by bees so that they included a certain amount of nectar or honey which Synge felt might have influenced the results. She decided that individual colony preferences for certain pollens do not exist, but that specific pollen preferences are common to bees in general.

In 1955 Levin and Bohart continued the work of Synge by designing experiments to find out whether preferences for pollen were evident when pollens were offered to bees outside the hive under more natural conditions. They concluded that some pollens are more attractive to bees than others even when separated from the colour patterns, structures, and perfumes normally associated with the flower. They also decided that the freshness of the pollen, its moisture, sugar, and protein content had little influence on the choice of the bees. Tests indicated that colour was unimportant as a factor in pollen attractiveness. The odour of the pollen was the only factor of those studied that appeared to have a positive correlation with the selection of pollens.

Intermill (1961) treated pollens with solvents and found that all pollens contained some attractant that was soluble in either alcohol or ether. He offered bees that had no previous experience in collecting pollen, extracts of pollen and found they preferred some to others.

Doull (1966) noted that pollens of Eucalyptus spp. and other Australian plants differ in their attractiveness to pollen collecting bees.

MATERIALS AND METHODS

THE STUDY AREA

Bees were kept for the summers of 1965 and 1966 on the horticulture section of Parkland Farm about 2 miles south of the main campus of the University of Alberta. Figure 1 is a land use map of the area over which the bees were likely to forage. Figure 2 is a detailed map of the farm area showing the planting plans for 1965 and 1966.

THE BEES AND THE POLLEN TRAPS

Pollen collections were made during the summers of 1965 and 1966.

In Northern Alberta bees are not overwintered so colonies used in this study were imported from California each spring.

In 1965 two 2 pound packages arrived on 6 April and as the weather was unfavourable, they were installed on 7 April in a position protected from the North and West by a house. The hives were wrapped with black polythene sheeting to absorb solar radiation. From installation until 4 May the bees were fed a 2:1 sugar syrup with a pinch (about 1.5 gm) of sulphadiazol added for American Foul Brood control. There was no pollen present in the combs of the brood chamber and no pollen supplement was added to the feed. On 30 April the colonies were moved one half mile to their permanent site (Figure 2).

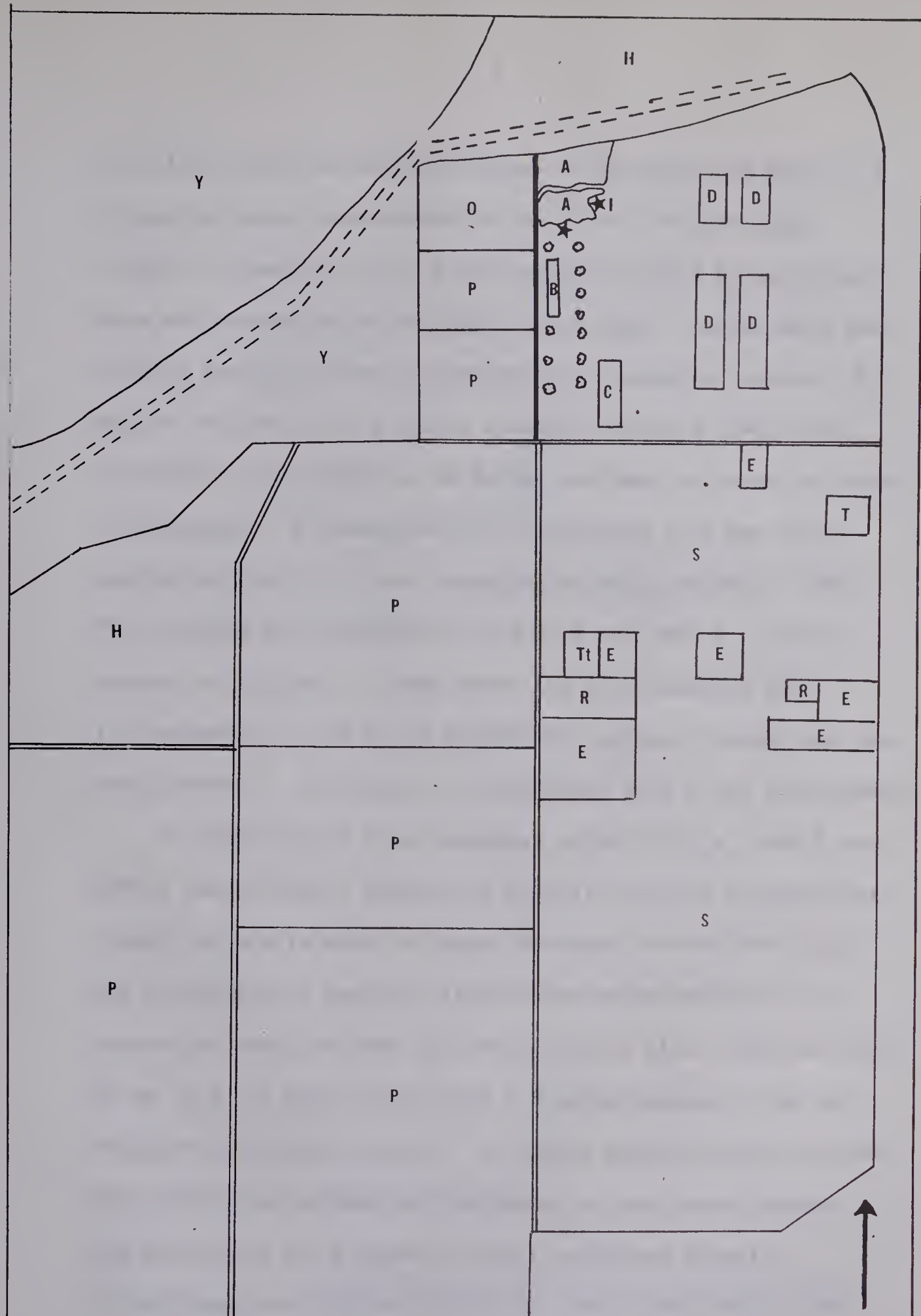


Figure 2: Planting Plan of the Farm Area in 1965 and 1966.

- | | | |
|------------|---|-------------------------|
| <u>Key</u> | A = Aspen copse surrounded by lilac | R = Red Clover |
| | B = Alsike clover during 1965 only | S = Cereal Crops |
| | C = Raspberry | T = Rape During 1966. |
| | D = Tulips | Tt = Rape During 1965 |
| | E = Alfalfa | Y = Sweet Clover |
| | H = Houses and Ornamental Plants | ----- = Belgravia Road |
| | O = Ornamental Plants | ⊙ = Apple & Plum Trees |
| | P = Pasture with White Dutch Clover and Dandelion | ★ = Hives During 1965 |
| | | ★ = Hives During 1966. |

The site chosen was well protected to the North and West by a stand of aspen associated with wild rose, and was ideal except for dampness. The hives were surrounded by grass and this was controlled by mowing in the summer. Boards were used to keep the grass from growing over the alighting boards. A pollen trap based on a design by Smith and Adie (1963) was installed on each hive on 30 April, and kept in operation until 10 September. A galvanized iron collecting tray was used instead of the cloth tray described by Smith and Adie (1963). The colonies are referred to as 1965 A and 1965 B. 1965 B swarmed on 30 June. A week after the last sampling date (10 September), 1965 A was killed with calcium cyanide and the honey removed. An attempt to overwinter 1965 B was unsuccessful.

In 1966 three 2 pound packages, called 1966 A, 1966 B and 1966 C respectively, arrived on 5 April and were installed on 6 April at a site about 20 yards Southwest of the 1965 site. The colonies were amongst lilac bushes which afforded less protection from the West than the previous site. They were fed 78 oz of a 2:1 sugar syrup with 1.5 gm terramycin added for American Foul Brood control. No pollen supplement was fed but some pollen was present in the frames of the brood chambers. The hives were not wrapped in black polythene sheeting. Pollen traps were placed on colonies 1966 A and 1966 B. A modified pollen trap (Figure 3) was installed on the colony called 1966 A on 18 May. This trap was in operation until 20 August. A swarm left 1966 A on 2 July. A trap was installed

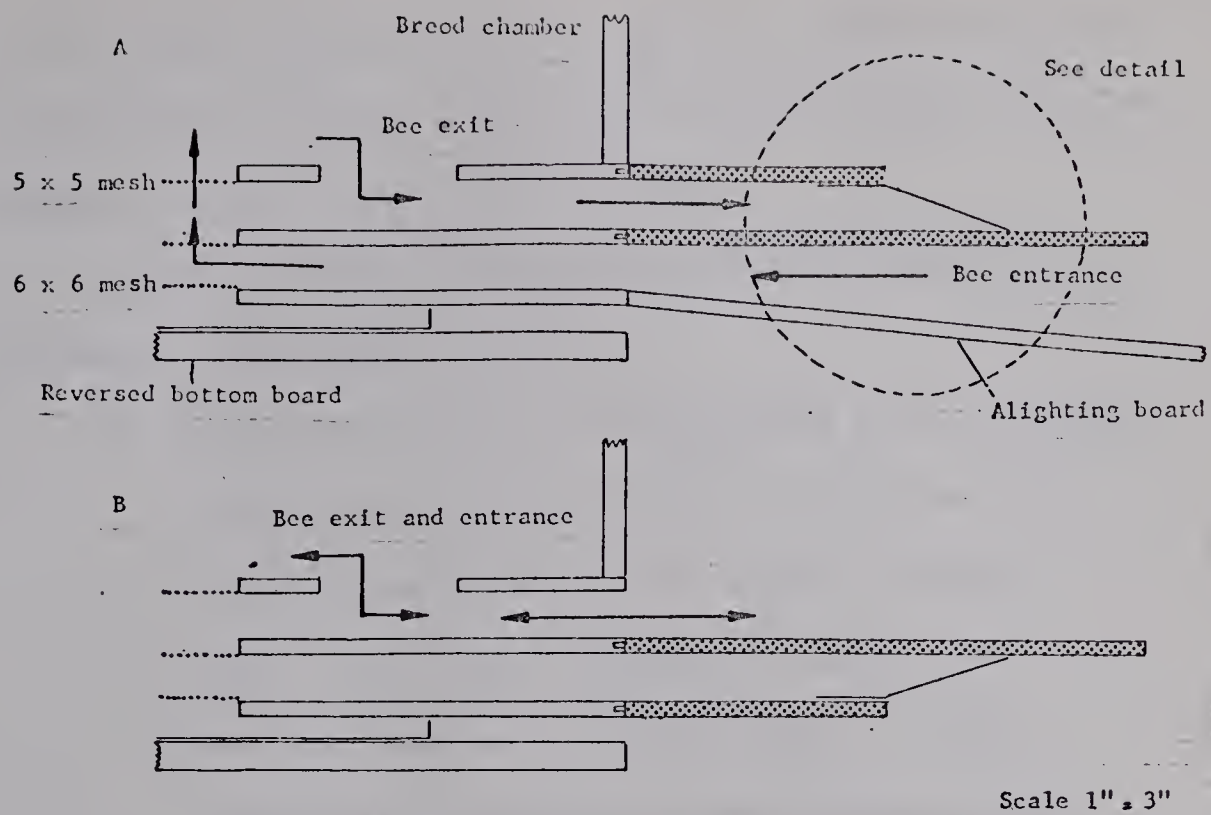


Figure 3: Modified entrance to pollen trap.

- (a) Pollen trap in use
- (b) Pollen trap not in use showing device allowing unrestricted entrance and exit of bees.
- (c) Detail from A showing arrangement of bronze weather stripping - $\frac{2}{3}$ actual size.

on the colony 1966 B on 6 July. Due to a malfunction it was not possible to remove the pollen collecting tray, so pollen samples were not taken from the colony.

During 1965 several problems arose concerning the operation of the pollen traps.

- (a) Water collected in the galvanized iron collecting tray on rainy days and did not drain away even after a number of holes were bored through the tray. As a result a number of samples were lost. This was overcome in 1966 by using a double thickness of muslin stretched across a wooden frame for a collecting tray.
- (b) The sliding screen was sealed in with propolis.
- (c) Bees were entering the hive through the exits thus bypassing the wire gauze.

The last two problems were overcome by modifying the entrance of the pollen trap, illustrated in Figure 3.

THE POLLEN SAMPLES

The pollen collected in the trays was removed into polythene bags every fourth day. The volume and gross weight of each sample were measured as soon as possible. Ten pollen pellets taken at random from each sample were weighed and the average weight calculated. Two 5g sub-samples from each sample were dried in an oven at approximately 60°C for eight days and the weight of the total sample of pollen was calculated.

In 1965 the remainder of the pollen was stored at -10°C pending identification and further study. In 1966 the pollen was stored in tightly closed polythene bags at room temperature. For identification approximately 5 g of pollen were removed from each sample and the number of pellets counted. These were sorted into different plant genera by colour and four or five pellets of each genus stained with Calberla's solution (Brown 1960). Identification was by comparison with reference slides prepared from pollen samples taken direct from plants, and the use of drawings and colour charts in Hodges (1952).

FACTORS INFLUENCING THE AMOUNTS OF POLLEN COLLECTED BY BEES

REVIEW

Much work has been done on the factors influencing the flight activities of bees. Recordings of the numbers of bees leaving and returning to the hives have been made with electric counters (Lundie 1925, Brittain 1933). Only a proportion of the bees leaving the hive are pollen collectors. Filmer (1932) found during pollination studies in orchards that the pollen collectors in the total field force varied from 15.7 - 39.6%. Lindauer (1952) found that the proportion of pollen collectors increased when a colony was fitted with a pollen trap.

Hutson (1926), during studies on flight activity in orchards during blossoming time, found that the climatic factors directly affecting flight were temperature, moisture, sunlight, and air movement. He concluded that temperature was not an important factor, humidity exerted little influence and that precipitation stopped flight. Sunlight increased flight and wind reduced it. He observed little flight at wind speeds greater than 25 mph.

Lundie (1925) worked on flight activities of bees in Maryland. He showed that the conditions for optimum bee activity in early spring were not the same for summer. Thus comparisons of conditions can only be meaningful if the days under consideration are close together.

He stated that any one factor may be at an intensity unfavourable for flight and that in the early part of the season low temperature is more limiting than any other factor. A study of the temperature at which flight commenced on each day of his investigation showed that under a particular set of conditions the flight commencement temperature does not vary more than 4 - 5 F degrees, the mean however, is not uniform throughout the season. In April flight usually began between 53.6 F and 57.2 F, in May between 57.2 F and 60.8 F, in June and July between 55.4 F and 80.6 F but most frequently between 66.2 F and 77 F, showing that at this time temperature is not often a factor in retarding the commencement of flight.

He found that on dull overcast days bees do not begin

their flight until the temperature has risen at least 3.6°F higher than the usual flight commencement temperature for the period.

He considered the internal condition of the colony to be important in determining the temperature at which flight would begin. Strong colonies commence their flight at lower temperatures.

He observed marked influence of storms and rain on bee activity. A storm, even without precipitation causes practically all the field force to return to the hive and thus may reduce a total day's flight by 7.4 to 9.6%. Showers, if heavy, produce the same effect as a severe storm. He considered this was primarily a response to the change in light intensity.

Lundie gathered little data on the effect of wind on flight. One record suggested that a velocity of 10 mph is the minimum velocity appreciably affecting flight, however, on another day he observed active flight with a wind velocity as high as 14 to 17 mph.

Phillips (1930) stated that the flight of bees is limited by temperature, wind, and moisture. At 60 F short flights are possible, at 65 F free flight and at 70 F full flight. He noted that a 25 mph wind stops flight whilst lower velocities reduce it. He stated that sunshine is not necessary for flight, but cloudy weather keeps bees close to the hive. He observed that a sudden shower will reduce a days flight by the field force by 10% or more, and rain or mist will stop it completely. De Ong (1925) gives tables to show that rain stops the flight of bees

even at temperatures of 52 F to 70 F, while on clear days bees work at all temperatures above 48 F.

Marshall et al.(1929) stated that bees are most active on bright warm days, that they do not fly readily at temperatures below 52 F to 56 F, and that a 25 mph wind is unfavourable to activity. He observed that bees prefer to fly against the wind when moving to the field, and with it when returning to the hive. Park (1923) noted that bees made little progress against a wind of 15 mph.

Brittain (1933) found that bees worked well at temperatures up to 80 F but the number working at over 90 F was insignificant. He considered that with all other conditions favourable, the temperature usually given as the minimum effective temperature for unlimited flight,(65 F), was higher than might be expected but decided that at 70 F maximum flights could be expected. He concluded that sunlight is an important factor influencing the activity of bees, but alone will not cause them to work if the temperature is low.

He carried out studies throughout the day with solar radiation and concluded that there is a upward trend of bee activity corresponding with increasing light values; and a corresponding decrease when the light reading falls off during the afternoon, or from the effects of cloud, haze, or fog at anytime during the day. He observed that within the temperature range of bee activity light has a greater influence than slight changes in temperature. This bears out Lundie's (1925)

statement that the temperature at which bees begin to reduce their flight activity in the afternoon is from 2 to 17 F degrees higher than that at which they become active in the morning, a phenomenon he postulated to be due to the waning light.

Brittain (1933) found that humidity had little influence on bee activity.

Todd and Bishop (1940), after considering pollen collection stated that wide daily fluctuations in pollen yield are due to the influence of weather factors on bee activity as well as on vegetation. Atmospheric conditions affect the dehiscence of anthers and opening of flowers. Synge (1947) found a correlation between the number of loads of red clover pollen gathered and the maximum daily temperature. This was shown to be caused mainly by the increased number of red clover flowers opening at higher temperatures. She considers this occurs in other plant species.

Todd and Bishop (1940), when considering factors other than weather effects on the amounts of pollen collected by bees, stated that the seasonal trends in a pollen collection cycle correspond to the flowering of the main pollen sources. The peaks in the pollen cycle do not occur during peaks in colony population but are correlated with the blooming of a good pollen source. Low periods in a cycle occur when the pollen is meagre.

Brittain (1933) states that the availability of food in the form of either nectar or pollen has a profound effect upon the

activity of bees; exhaustion of supplies being followed by a slackening in flight.

Filmer (1932) demonstrated that the proportion of pollen gatherers in a field force increased with the quantity of brood.

Ribbands (1953) considers Lindauer's (1952) observation that the proportion of pollen gatherers increases when a colony is fitted with a pollen trap, indicates that the needs of a colony determine the proportion of the pollen gatherers in the field force and hence the amount of pollen collected in the trap.

RESULTS AND DISCUSSION

Two sets of quantitative data were obtained from my colonies in 1965 and one set in 1966.

Meteorological data for the Edmonton Municipal Airport about 6 miles North of the site of the bees was obtained from the Department of Transport.

Only Park (1923) found the mean speed of a returning forager to be 14 mph. Other workers report windspeeds ranging from 10 mph to 25 mph at which flight activities were affected. I chose 14 mph, in my study, as the windspeed at which flight would cease as far as pollen collection and the transportation of pollen loads was concerned.

A combined daily index for the two factors, hours of bright sunshine and mean windspeed, was calculated as follows:

$(14 - \text{windspeed in mph}) \times \text{hours of bright sunshine}$

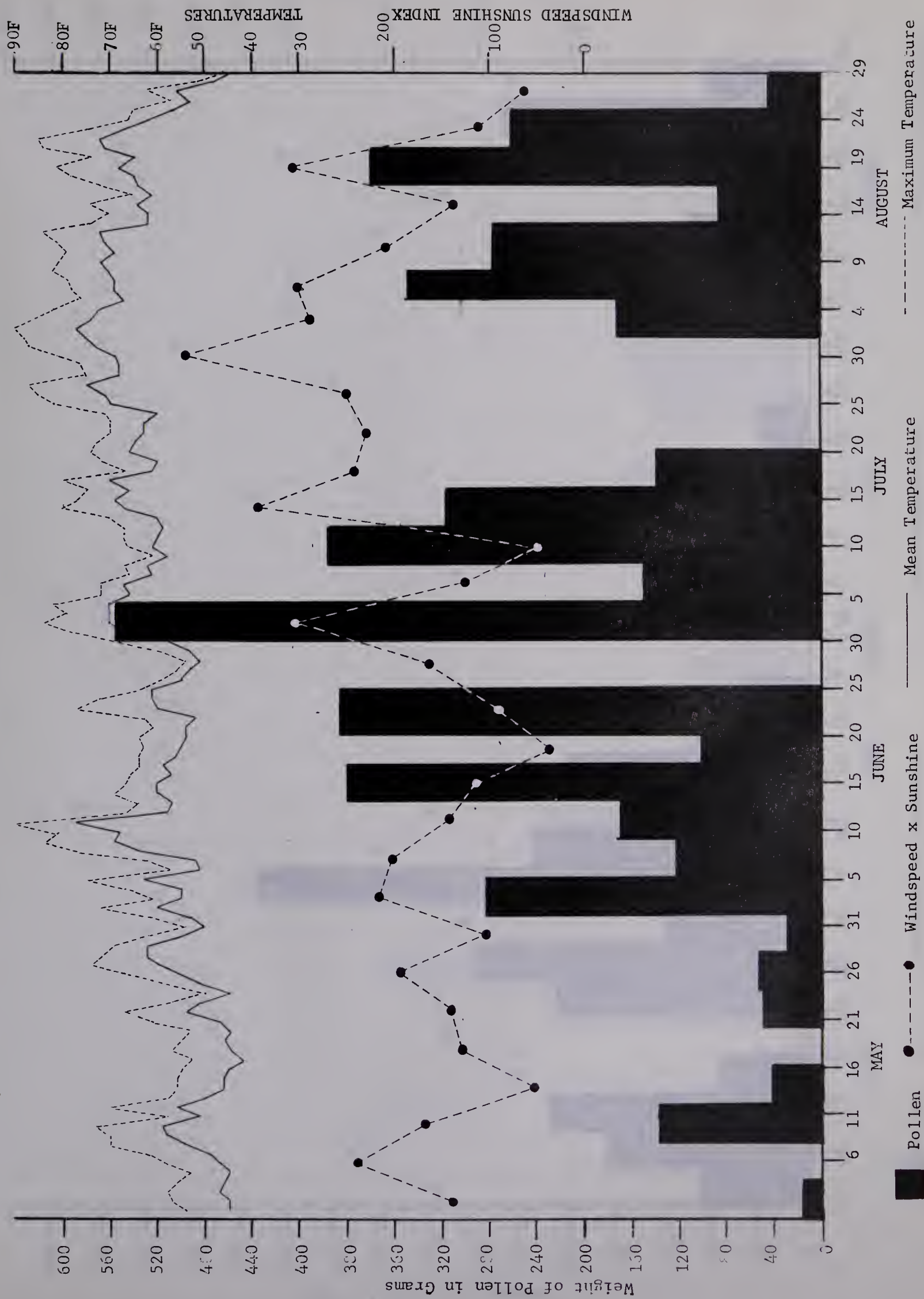


Figure 4a: The Relationship Between the Weights of Pollen Collected, the Daily Mean Temperature, the Daily Maximum Temperature, Hours of Sunshine and Windspeed Over the 1965 Season, Hive A.

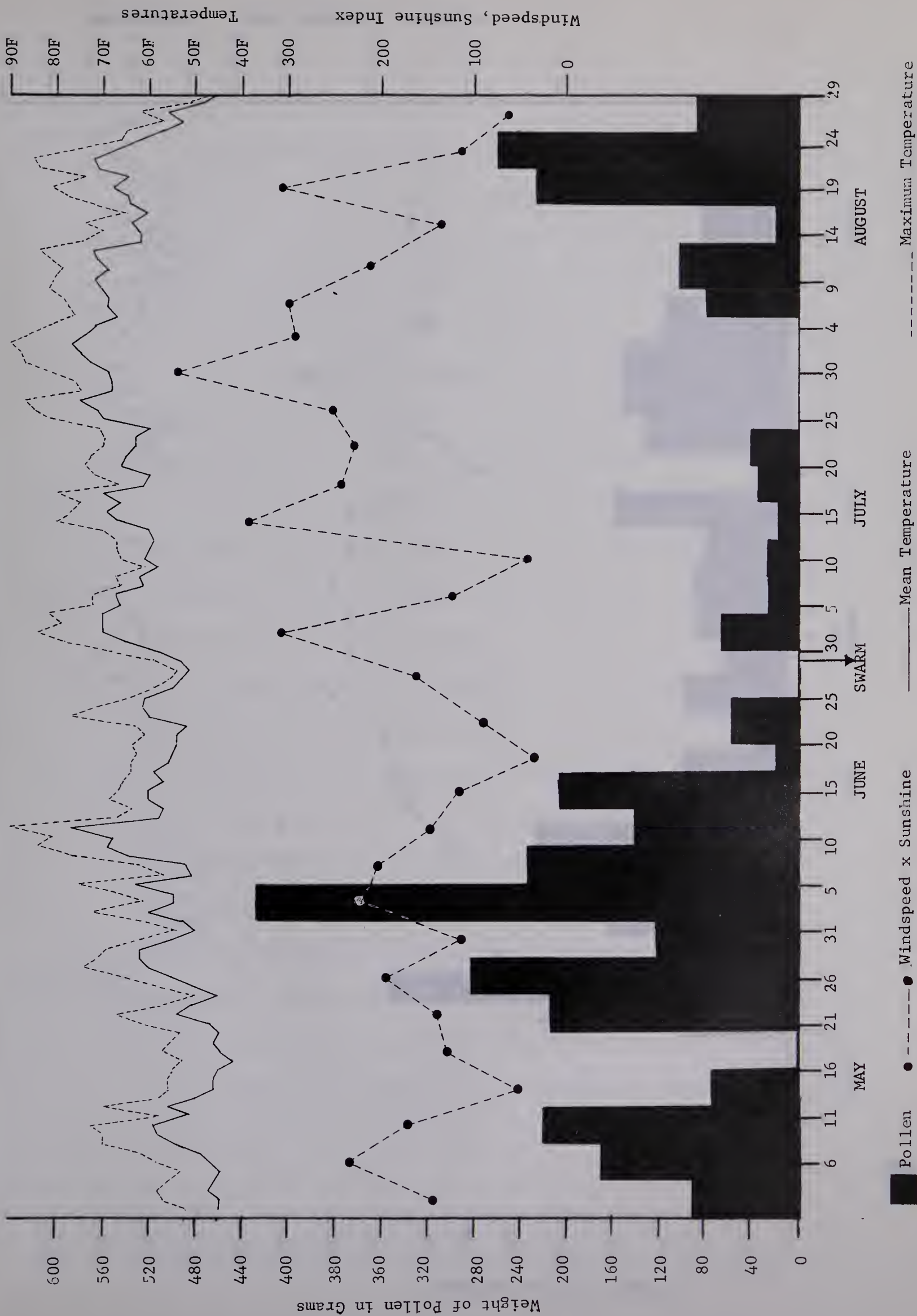


Figure 4 b: The Relationship Between the Weights of Pollen Collected, the Daily Mean and Minimum Temperatures, Hours of Sunshine and Windspeed Over the 1965 Season, Hive B.

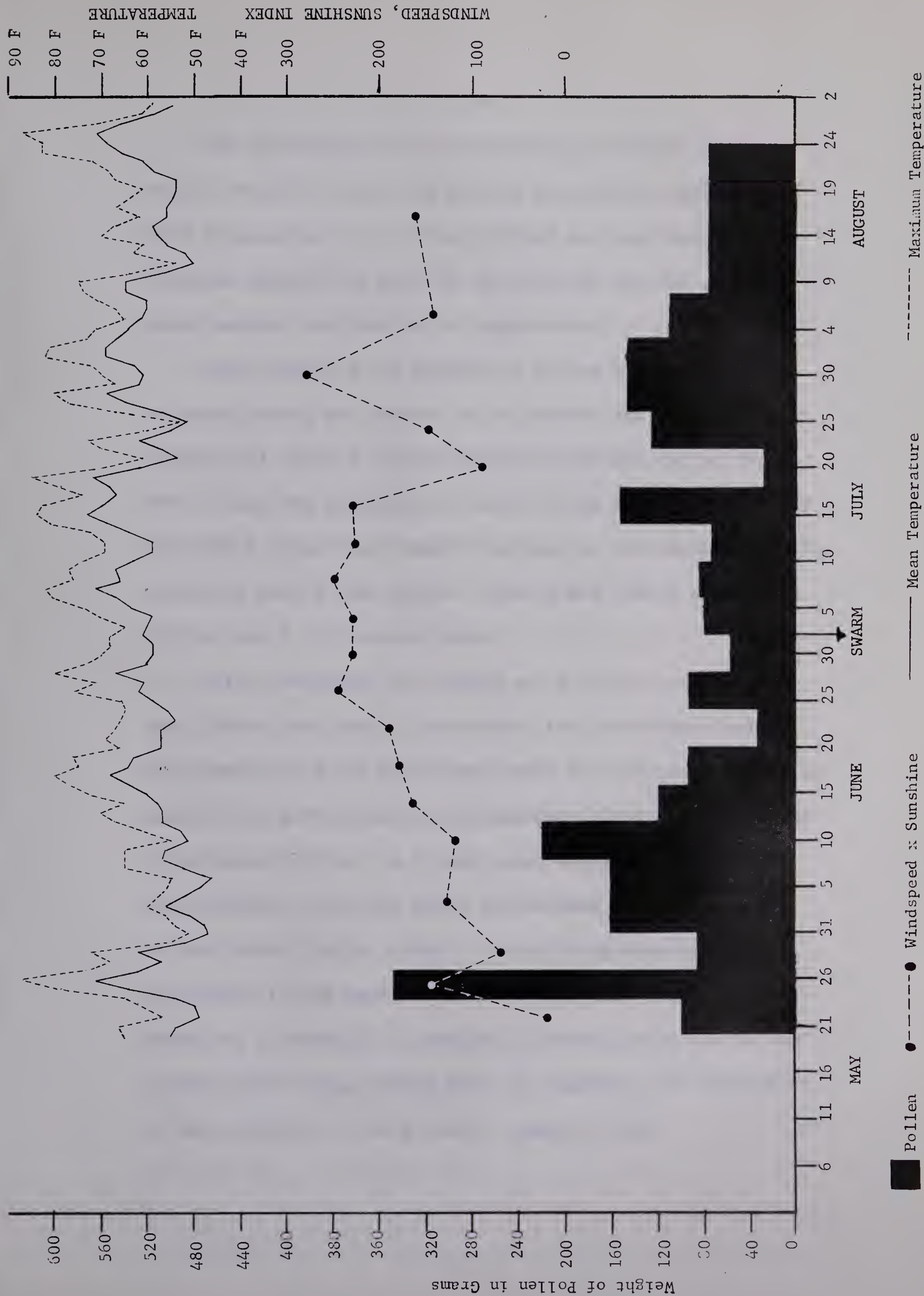


Figure 4c: The Relationship Between the Weights of Pollen Collected, the Daily Mean and Minimum Temperatures, Hours of Sunshine and Windspeed Over the 1966 Season, Hive A.

The quantitative data, consisting of the dry weight of pollen trapped in four day periods are plotted against the date (Figure 4a, b, c). Also plotted are the windspeed-sunshine indices for each of the four-day periods and the daily maximum and mean daily temperatures.

When comparing the amounts of pollen brought into the colonies during the season, it is noticed that 1965 A (figure 4z) shows a peak of pollen collection during the end of June and beginning of July, whilst 1965 B (Figure 4b) and 1966 A (Figure 4c) show a decrease in the amount of pollen collected during this period. 1965 B and 1966 A swarmed on 29 June and 2 July respectively.

Before swarming, egg laying and field activities slow down. (Peer pers comm.) Soon after the first queen cells have been sealed the old queen leaves the hive accompanied by many of the worker bees. Approximately eight days after the prime swarm has left, a virgin queen emerges and after approximately five days mates and becomes the laying queen of the colony (Butler 1959). The pollen gathering force is diminished in two ways, by loss of many bees with the prime swarm, by a reduction in emergence of young bees due to the slowing down of egg laying prior to swarming, and the period of approximately 13 days when no eggs are laid.

Therefore the condition of the colony has a marked effect on the seasonal peaks of the pollen cycle. According to Todd and Bishop (1940), the condition of the colony is a minor factor, but they do not state whether any of their colonies swarmed whilst being studied. They state that the day to day variations in the amounts of pollen are due to the influence of the weather on bee activities.

From my data it should be noted that in 1965 (Figure 4a, b) from 30 June until 25 August the daily mean temperature was above 57°F, the temperature at which Brittain (1933) observed fair activity. This temperature was not a limiting factor in pollen collection during this period, bearing out Lundie's (1925) statement that at this time of year temperature does not often retard the commencement of flight.

My data also shows that effects of windspeed and hours of bright sunshine are generally closely correlated with the quantities of pollen collected from the traps. There are some exceptions however. In the data for 1965 A (Figure 4a), when considering the wind speed-sunshine index, the totals for the periods June 14 - 17, July 9 - 12, are higher than predicted. A super was added to the hive at the beginning of each of these four-day periods. Thus the increase in pollen collection could be due to the increased space within the hive. In 1965 B (Figure 4b) the totals for May 9 - 12, June 14 - 17, are higher than expected. The period June 14 - 17 corresponds to the addition of a super mentioned above. The pollen trapped during the period May 9 - 12 corresponds well to the higher maximum

and mean temperatures experienced at that time.

In 1966 (Figure 4c), the pollen trapped during the period June 9 - 12 is greater than expected due perhaps to the daily maximum temperatures at this time. Pollen collected during June 16 - 20, 21 - 24 is lower than expected. The totals for June 16 - 20 and 21 - 24 may be explained in the light of the swarm which emerged on 2 June and the low mean temperature on June 23.

Very high maximum temperatures increase the pollen gathering activities, for example the total of period July 1 - 4, 1965 A (Figure 4a) and May 25 - 27, 1966 A (Figure 4c). However, Brittain's (1933) statement that few bees work at temperatures round 90 F appears to be confirmed when considering the pollen collected during the periods June 10 - 13, August 2 - 5, by 1965 A (Figure 4a) and June 10 - 13 by 1965 B (Figure 4b).

The direct influence of storms and precipitation on the amounts of pollen collected was not gauged as their effects are contained in the hours of bright sunshine data.

Thus the condition of the colony appears to be the most important long term factor governing pollen collection by bees. The weather conditions cause the day to day fluctuations in the amounts of pollen brought into the hive.

POLLEN SOURCES

Many lists of pollen producing plants with their periods of pollen production are available. However, little work has been done on the significance of the amounts of pollen collected from different plant species or on the range of plant species the bees forage for pollen.

Betts (1920, 1935), Clements and Long (1923), and Brittain and Newton (1933), attempted to measure the degree of flower constancy of bees by determining the percentage of mixed pollen loads brought into the hive. This ranged from 0 to 38%. Maurizio (1954) in a more extensive study found the percentage of mixed loads was usually between 1 and 3%. Brittain and Newton (1933) concluded that constancy depends on the availability of the pollen.

In general bees restrict their activities to a particular portion of a crop. Butler (1959) stated that bees may sometimes leave the crop they are foraging and sample pollen from another crop. If the new source is more satisfactory, they will forage on this.

Betts (1928) discussed the significance of the number of plant species worked for pollen by bees. She considers that a sharp rise in the number of plant species visited is a sign that bees are short of pollen. If the source plants are not producing sufficient pollen, fresh pollen sources will be sought and the number of species visited thus will increase. Therefore the number of plant species worked for

pollen will vary as the season progresses, being dependent not only on the nature of the pollen supply but also on the condition of the colony.

The outstanding feature of my data (Figure 5) is the variation between the amounts of pollen collected from different plant sources by the two colonies studied in 1965. Todd and Bishop (1940), Eckert (1942), and Synge (1947), mentioned similar problems. Synge (1947) suggested reasons for the phenomenon. Firstly, colonies may exhibit individual pollen preferences, however, she decided later that these preferences were common to bees in general. Secondly, though little is known about how foragers from a colony become allotted to a particular crop, or how a change over from a failing source is effected, she considered that it was due to a complex of factors governing both the internal economy of the colonies, the external relationships of the foraging bees and the flora. These factors include the demand for pollen by the colony, the method of organization of the field force for gathering pollen nectar and water, the behaviour of flowers, the time of pollen dehiscence and its ease of collection, the amount of pollen available and competition from other insects. All these factors affect the species of plants from which the bees collect pollen.

Pollen succession data for 1965 and 1966 (Figure 5) showed the succession to be the same, however during 1966 Alsike Clover was not available, and was replaced by Sweet Clover.

Sweet Clover was abundant on Belgravia Road (Figure 2) during 1965 and 1966 but was cut and thus flowered very sparsely during 1965.

During late July and August 1965 White Dutch Clover was an important source. In 1966 it was a minor source. It was available in approximately the same quantities each year. I can offer no explanation for this other than the phenomenon of variation between colonies and the plants from which pollen is collected. It should be noted that during this time the number of plant species worked for pollen was higher in 1966 than in 1965. It is interesting that in 1965 alfalfa pollen was first recorded in the period August 2 to 5, whilst in 1966 it was first recorded in the period July 3 to 6. Bees are reluctant to collect pollen from alfalfa due to the tripping mechanism of the flower. I consider that the early collection of alfalfa pollen in 1966 was due to the absence of Alsike Clover, a major source.

A seasonal list of pollen sources is given in Table 1.

Only 29 species, of which 12 are considered important, are recorded as being collected by bees in this area. Percival (1947) during a study in South Wales, recorded bees visiting 86 species of plants for pollen, however large amounts of pollen were collected from only 2 species. Of the 86 species observed by Percival, 20 pollens remained unidentified.

The small number of species I recorded may be due to the following reasons. Firstly, the sampling method used

TABLE 1

Seasonal List of Pollen Sources

Time	Common Name	Scientific Name
Early-mid May	*Willow	<u>Salix</u> spp
	Poplar	<u>Populus tremuloides</u> Michx
	Dandelion	<u>Taraxacum officinale</u> Weber
Mid-late May	*Willow	<u>Salix</u> spp
	*Dandelion	<u>Taraxacum officinale</u> Weber
	*Apple	<u>Malus</u> spp.
	*Plum	<u>Prunus domestica</u> L.
	Tulip	<u>Tulipa</u> spp.
	Larch	<u>Larix laricina</u> (DuRoi) Koch
Early-mid June	*Apple	<u>Malus</u> spp.
	*Plum	<u>Prunus domestica</u> L.
	Dandelion	<u>Taraxacum officinale</u> Weber
	Wild Rose	<u>Rosa acicularis</u> Lindl.
	Honeysuckle	<u>Lonicera tatarica</u> L.
	Lilac	<u>Syringa</u> spp
Mid-late June	*Apple	<u>Malus</u> spp
	*Alsike Clover	<u>Trifolium hybridum</u> L.
	White Dutch Clover	<u>Trifolium repens</u> L.
	*Wild Rose	<u>Rosa acicularis</u> Lindl.
	Dandelion	<u>Taraxacum officinale</u> Weber
	Hawthorn	<u>Crataegus</u> spp
	*Lilac	<u>Syringa</u> spp
	Oriental Poppy	<u>Papaver</u> sp

Table 1 - Continued

Time	Common Name	Scientific Name
Mid-late June	Raspberry	<u>Rubus</u> sp.
	Rape	<u>Brassica</u> sp.
	Honeysuckle	<u>Lonicera tatarica</u> L.
Early-mid July	*Alsike Clover	<u>Trifolium hybridum</u> L.
	*White Dutch Clover	<u>Trifolium repens</u> L.
	*Wild Rose	<u>Rosa acicularis</u> Lindl.
	*Sweet Clover	<u>Melilotus alba</u> Desv. <u>M. officinalis</u> (L) Lam.
	Lilac	<u>Syringa</u> spp
	Honeysuckle	<u>Lonicera tatarica</u> L.
	Dandelion	<u>Taraxacum officinale</u> Weber
	Sainfoin	<u>Onobrychus</u> sp.
	Oriental Poppy	<u>Papaver</u> sp
	*Rape	<u>Brassica</u> sp.
	Alfalfa	<u>Medicago Sativa</u> L.
	Raspberry	<u>Rubus</u> sp.
	**Evening Primrose	<u>Oenothera biennus</u> L.
Mid-late July	*Alsike Clover	<u>Trifolium hybridum</u> L.
	*White Dutch Clover	<u>Trifolium repens</u> L.
	*Sweet Clover	<u>Melilotus alba</u> Desv. <u>M. officinalis</u> (L) Lam.
	Dandelion	<u>Taraxacum officinale</u> Weber
	Wild Rose	<u>Rosa acicularis</u> Lindl
	Honeysuckle	<u>Lonicera tatarica</u> L
	Rape	<u>Brassica</u> sp.

Table 1 - Continued

Time	Common Name	Scientific Name
Mid-late July	Lilac	<u>Syringa</u> sp
	Raspberry	<u>Rubus</u> sp
	**Evening Primrose	<u>Oenothera biennis</u> L.
	Red Clover	<u>Trifolium pratense</u> L.
Early-mid August	Alsike Clover	<u>Trifolium hybridum</u> L
	*White Dutch Clover	<u>Trifolium repens</u> L.
	*Sweet Clover	<u>Melilotus alba</u> Desv. <u>M. officinalis</u> (L) Lam.
	*Red Clover	<u>Trifolium pratense</u> L.
	*Alfalfa	<u>Medicago sativa</u> L.
	Bindweed	<u>Convolvulus</u> spp
	Fireweed	<u>Epilobium angustifolium</u> L
	Raspberry	<u>Rubus</u> sp
	**Mullein	<u>Verbascum thapsus</u> L.
	Rape	<u>Brassica</u> sp
	**Veronica	<u>Veronica</u> sp
	**Cucurbit	<u>Echinocystis</u> sp
	Dandelion	<u>Taraxacum officinale</u> Weber
	*White Dutch Clover	<u>Trifolium repens</u> L.
	Sweet Clover	<u>Melilotus alba</u> Desv. <u>M. officinalis</u> (L) Lam
Mid-late August	Red Clover	<u>Trifolium pratense</u> L.
	Dandelion	<u>Taraxacum officinale</u> Weber
	Alfalfa	<u>Medicago sativa</u> L.
	**Mullein	<u>Verbascum thapsus</u> L.

Table 1 - Continued

Time	Common Name	Scientific Name
Early September	*Sweet Clover	<u>Melilotus alba</u> Desv. <u>M. officinalis</u> (L) Lam.
	Red Clover	<u>Trifolium pratense</u> L.
	*White Dutch Clover	<u>Trifolium repens</u> L.
	Dandelion	<u>Taraxacum officinale</u> Weber
	Aster	<u>Aster</u> spp.

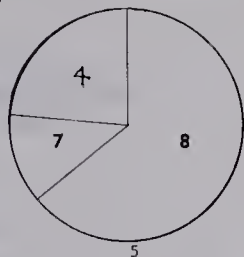
* Major Pollen Source In Time Period.

** Identified From Pollen Alone.

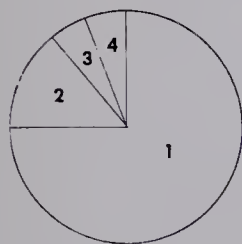
FIGURE 5 A
POLLENS COLLECTED BY
HIVE A, 1965

KEY

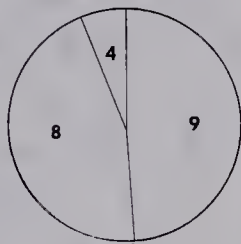
1. Willow
2. Poplar
3. Dandelion
4. Other - All less than 10% of total.
5. Apple
6. Plum
7. Rose
8. Alsike Clover
9. White Dutch Clover
10. Sweet Clover
11. Lilac
12. Hawthorn
13. Crocus
14. Alfalfa
15. Red Clover
16. Rape



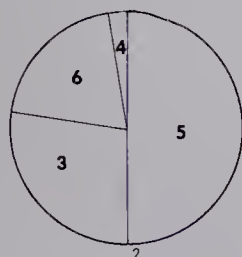
July 1-16
Sainfoin Honeysuckle
White Dutch Clover Lilac
Oriental Poppy Dandelion
Undetermined



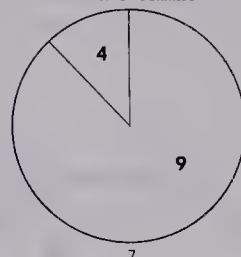
May 4-16
Other Undetermined



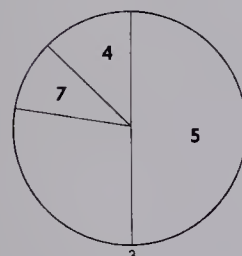
July 16-August 1
July 21-28 Missing
Other
Oriental Poppy
Rose
Undetermined



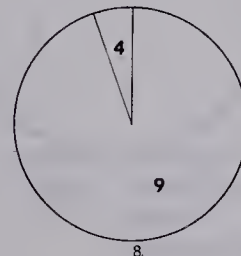
May 17 to June 1
May 17-20 Missing
Other Undetermined



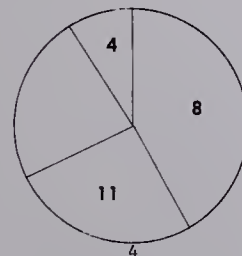
August 2-17
Other
Lesser Bindweed Undetermined
Fireweed Alfalfa
Dandelion Red Clover



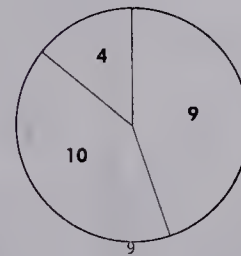
June 2 - June 17
June 14 - 17 Missing
Other Dandelion
Honeysuckle



August 18 - Sept. 7
August 26-29 Missing
Other Sweet Clover
Red Clover
Undetermined

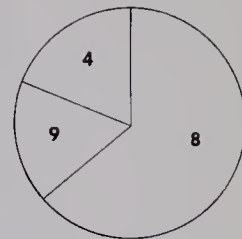


June 18 - 30
Only 22 - 25 June presented
Other Dandelion
Honeysuckle
Undetermined

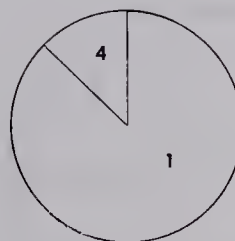


September 3 - 10
2 samples only
Other Undetermined
Dandelion
Red Clover

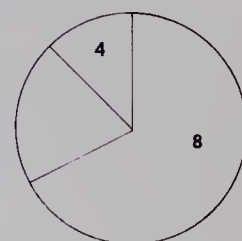
FIGURE 5 A
POLLENS COLLECTED BY
HIVE B, 1965



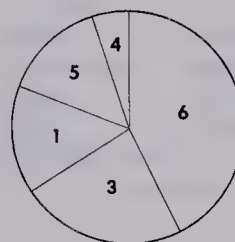
July 1 - 16
Rose Oriental Poppy
Undetermined Mullein
Dandelion Bindweed
Sainfoin Lilac



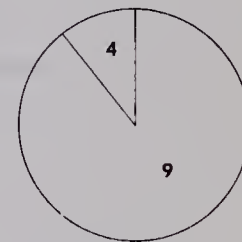
May 1 - 16
Other Dandelion
Populus
Undetermined



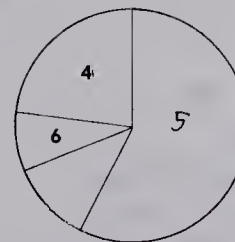
July 16-August 1
July 25 - August 1 Missing
Other Honeysuckle
Lilac
Rape
Unknown



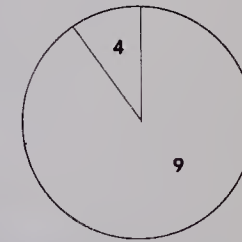
May 17 - June 1
Other Tulip
Larix
Undetermined



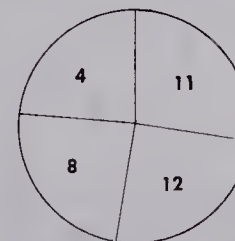
August 2 - 7
August 2 - 6 Missing
Other Red Clover
Dandelion
Fireweed



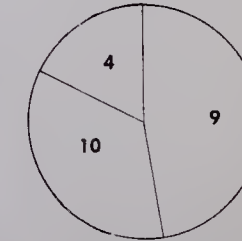
June 2 - June 17
Other Honeysuckle
Lilac
Dandelion
Undetermined



August 18 - Sept. 2
August 26-29 Missing
Other Red Clover
Fireweed
Dandelion



June 18 - 30
Other Apple
Rose
Undetermined
Apple

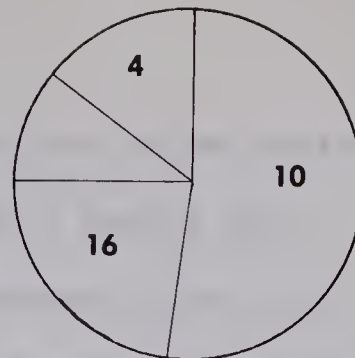


Sept. 2 - 10
Other Red Clover
Dandelion
Aster
Undetermined

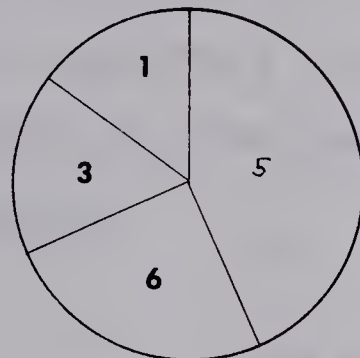
FIGURE 5 8
POLLENS COLLECTED BY
HIVE A, 1966

KEY

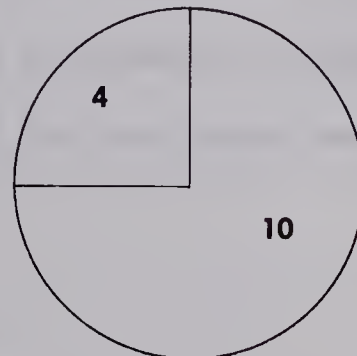
1. Willow
2. Poplar
3. Dandelion
4. Other - All less than 10% of total.
5. Apple
6. Plum
7. Rose
8. Alsike Clover
9. White Dutch Clover
10. Sweet Clover
11. Lilac
12. Hawthorn
13. Crocus
14. Alfalfa
15. Red Clover
16. Rape



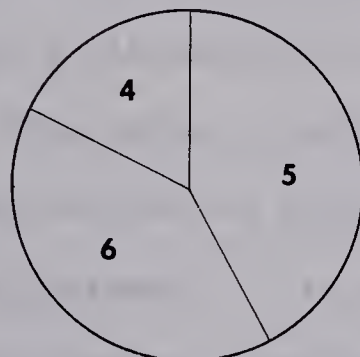
June 29 - July 14
Other Alfalfa
Dandelion
Raspberry
Undetermined



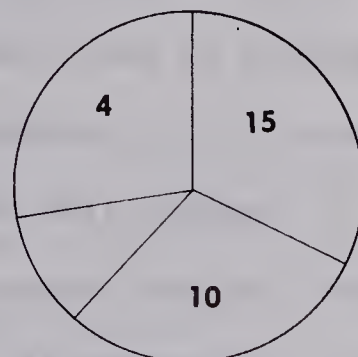
May 21 - 27



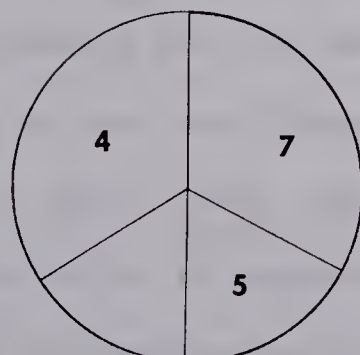
July 15 - 26
Lilac Honeysuckle
Dandelion Evening Primrose
Rose Red Clover
Rape Raspberry
Undetermined



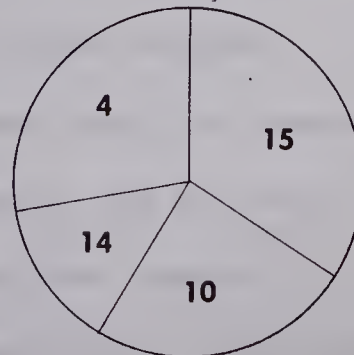
May 28 - June 17
Other Dandelion
Lilac
Undetermined



July 27 - August 16
July 27-30 Missing
Other Rose
Dandelion White Dutch Clover
Undetermined Raspberry
Fireweed Mullein



June 18 - June 29
Other Honeysuckle
Dandelion
Oriental Poppy
Raspberry
Lilac
Rape
Undetermined



August 17 - 25
Mullein
White Dutch Clover
Dandelion
Undetermined

would not be likely to take into account one or two pollen loads from a single species occurring in a sample from a four day period. Secondly, it may be because close and abundant pollen sources were available throughout the season. (Figure 2). Percival (1947) compared the quantities of pollen collected from each species with the abundance of the crop and decided that a strong positive correlation existed. Approximately 2% of the loads collected for this study were not identified.

THE POLLEN LOADS

According to Butler (1949) pollen is collected by the bee either deliberately or incidently while she is seeking nectar. When pollen is collected deliberately, it is mixed with honey carried out from the hive for this purpose; if collected incidently it is mixed with nectar from the flowers upon which the bee is working before it is packed into the corbiculae.

Parker (1926) reported that the manner in which bees gather pollen is not the same for every plant species. In gathering pollen from flowers of the open type, for example dandelion, apple, rose, rape and raspberry, the bee bites the anthers with its mandibles and pulls them towards its body with its forelegs while running rapidly over the flowers and packing pollen into the corbiculae. While working flowers of the closed type for pollen, for example clover, the bee

alights on the wings of the flower and separates the keel from the wings by forcing its forelegs between them. The pollen is gathered on the mouthparts and forelegs of the bee and is packed into the corbiculae while the bee is flying.

In collecting pollen from flowers of the catkin type, for example willow, the bees may alight at the base of the catkin, run up it a short distance, then fly away to pack the pollen gathered, returning to gather more pollen.

Sometimes the bee does not alight on the catkin, but may suspend itself in the air while brushing the anthers.

The pollen packing mechanism of the bees is described in great detail by Parker (1926). He stated that the mechanism is the same for all flowers on which he made observations.

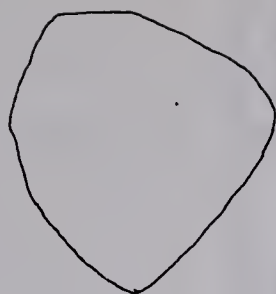
In 1923 Park stated that the weight of a pollen load depended on the species of plant from which the pollen had been collected. He found that elm loads weighed 12 mg, maize 14 mg, apple 25 mg, and hard maple 29 mg. Kellogg and Asquith (1934) stated that the average weight of pollen carried per bee was 12.4 mg. In my study the average pollen weight carried was 19.6 mg. A pollen load is made up of two pellets.

The relationship between the size of pollen pellet and the pollen grain and its ease of collection was investigated

as follows.

Twenty dry pollen pellets gathered from each of seven plant genera were kept overnight at 60°C and the mean weight of a pellet of each genus calculated. Two measurements were made on each pellet, the length parallel to the tibia as the pellet lies in the corbicula, and the thickness, at right angles to the bee's body. The width of the pellet, parallel with the body of the bee was considered to be a function of the width of the corbicula. This, in comparison with the variation of pellet can be regarded as constant. The pollen grains were examined under a microscope and the greatest diameters measured. The means and standard deviations were calculated for all measurements. Drawings (Figure 6) were made of the pollen grains and the texture of the exine was noted.

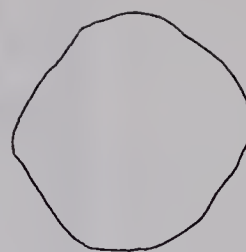
My results (Table 2 and Figure 6) show that the willow pollen grains were the largest, round to pyramidal, with very slight texturing of the exine. The rape pollen grains were the second largest and rounded in shape, the exine more heavily textured than the willow pollen grains. The dandelion pollen grains had the third largest diameter. The exine of these grains was highly sculptured. Crab apple grains were rounded in shape with a smooth exine. The sweet clover pollen grains were the second to smallest measured, with a very characteristic onion like shape and smooth exine. The raspberry pollen grains



Willow



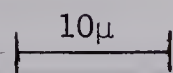
Rape



Dandelion



Crabapple



Rose



Sweet Clover



Raspberry

Figure 6: Pollen Grain Shapes and Relative Sizes.

TABLE 2

The Relationship Between Weight in Milligrams And Dimensions of Pollen

Pellets And Size And Sculpturing Of Constituent Pollen Grains

Pollen	Mean Weight Of Pellet	Mean Length Of Pellet +S.D. (No. of readings)	Mean Thickness Of Pellet +S.D. (No. of readings)	Mean Diameter of Pollen Grain +S.D. (No. of readings)	Sculpturing
Willow	10.45 mg	0.45 cm± 0.05 (20)	0.25 cm± 0.03 (20)	26μ± 0.70 (7)	Very slight
Crab Apple	9.30 mg	0.46 cm± 0.10 (19)	0.21 cm± 0.06 (19)	15μ± 0.70 (7)	Smooth
Rape	9.03 mg	0.42 cm± 0.09 (20)	0.23 cm± 0.10 (20)	17μ± 2.20 (6)	Slight
Rose	8.88 mg	0.44 cm± 0.11 (20)	0.21 cm± 0.10 (20)	14μ± 1.60 (7)	Smooth
Raspberry	8.48 mg	0.43 cm± 0.10 (19)	0.21 cm± 0.04 (19)	11μ± 1.40 (6)	Smooth
Sweet Clover	6.53 mg	0.37 cm± 0.10 (20)	0.20 cm± 0.05 (20)	13μ± 1.70 (6)	Smooth
Dandelion	6.10 mg	0.32 cm± 0.08 (20)	0.17 cm± 0.04 (20)	16μ± 1.70 (6)	Heavy

were the smallest recorded, almost perfectly spherical in shape with a smooth exine.

Pellets formed from pollen collected from willow were the largest recorded, followed by crab apple, rape, rose, raspberry, sweet clover and dandelion in that order. The weights of the pellets followed the same sequence except that the alfalfa pellet was lighter than both rose and raspberry pellets.

Willow, rape, rose, dandelion, and crab apple are abundant pollen producers for a complete pollen load may be collected from a single flower or flower group. I consider raspberry an intermediate pollen producer and sweet clover a poor producer of pollen. Weaver et al. (1953) observed a bee visit 494 sweet clover flowers before a full load was gathered.

In general it appears that the larger the pollen grain, the larger the pollen pellet formed by the bee. (Figure 7) Extreme sculpturing seems to have a negative effect on the size of the pollen pellet in the case of dandelion. Grains with a three dimensional triangular shape are generally formed into smaller pellets than those with a rounded shape. The effect of the pollen packing material, nectar or honey, on the size of the pollen pellet was not determined. Pollen pellets gathered from plants producing large amounts of easily available pollen tended to be larger than pellets from plants with little pollen requiring visits to many flowers before a load can be collected.

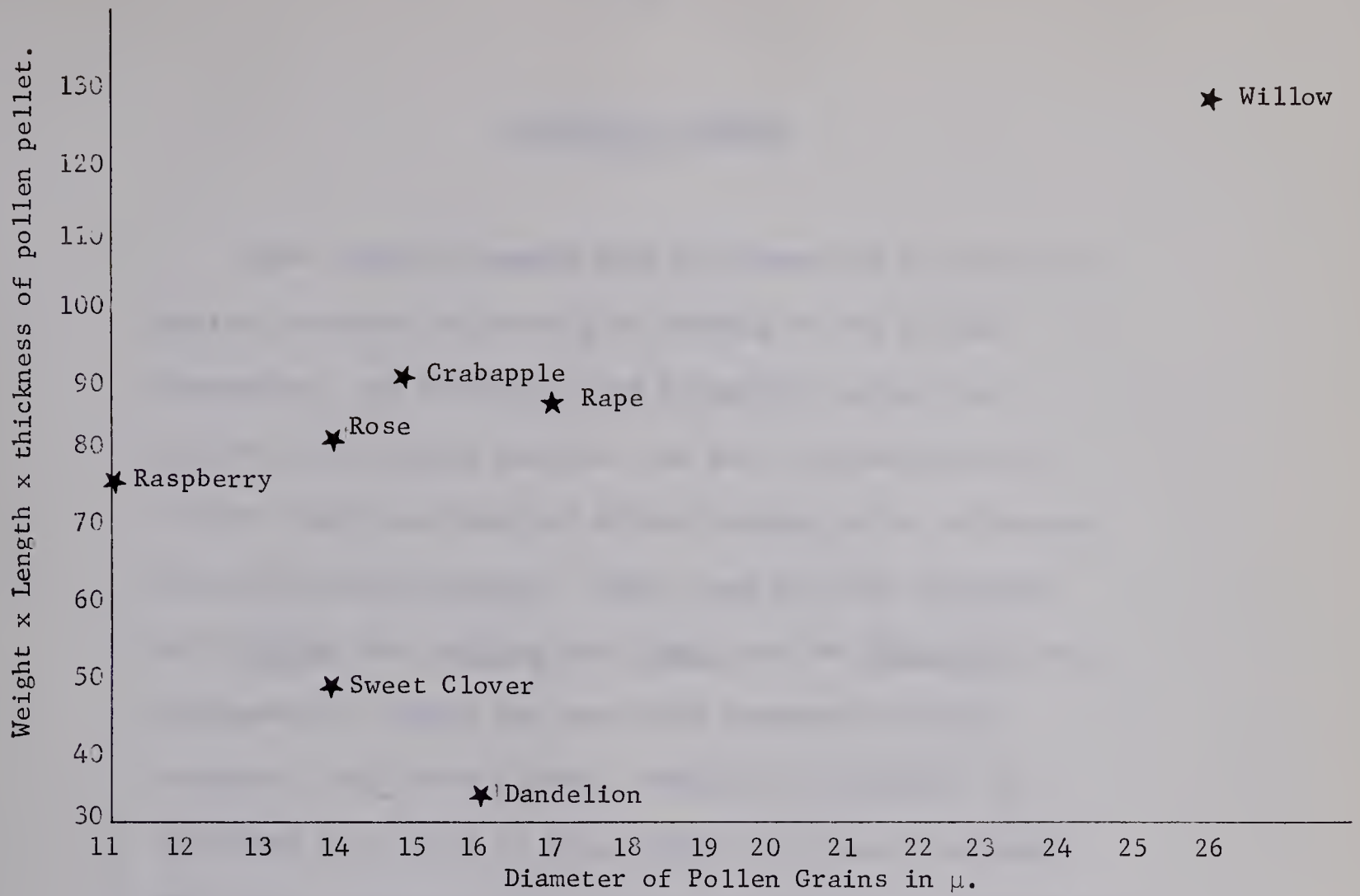


Figure 7: The Relationship Between the Dimensions and Weight of Pollen Pellets and the Diameter of Constituent Pollen Grains.

COMPETING INSECTS

Other insects compete with hive bees for a source of pollen by either collecting or feeding on the pollen themselves. An incidental and incomplete survey was carried out on these insects. As far as possible only insects that were observed either feeding on or collecting the pollen were captured. Other bees are most important with Bombus spp, Andrena spp, Osmia spp and Megachile spp represented. Bombus spp were very numerous on rape, raspberry, and sweet clover. Amongst the Diptera, the Syrphidae were found in large numbers on rape. Anthomyid flies were captured while licking the anthers of flowers with their proboscides. I was uncertain whether they were feeding on the pollen or licking nectar off the surface of the anthers. Members of two families of Coleoptera were captured, a curculionid in aspen and a chrysomelid (Orsodacninae) in wild rose. The beak and the body of the weevil were dusted over with pollen.

It is my opinion that, in the area under consideration, the pollen supplies were in such abundance that competition for pollen by other insects was not an important factor influencing the collection of pollen by the hive bees.

TABLE 3

Other Insects Visiting Pollen Sources

	Willow	Populus	Dandelion	Honey Suckle	Rose	Alsike Clover	Sweet Clover	Rape	Raspberry	Fireweed
Diptera:										
Anthomyiidae	X		X	X			X	X		
Unidentified Syrphidae	X						X	X		
<u>Elophilus latifrons</u> Lw								X		
<u>E. obscurus</u> Lw			X							
<u>Metasyrphus venustus</u> Mg			X							
<u>Mesogramma robusta</u> Met			X							
<u>Eristalis latifrons</u> Lw								X		
<u>Syrphus ribesii</u> L			X				X			
Unidentified Calliphoridae	X		X				X			
Muscidae			X		X					
Hymenoptera:										
<u>Megachile perihirta</u> Ckll.			X			X				
<u>M. melanophaea</u> Sm						X				
<u>M. dentitarsus</u> Sladen						X				

TABLE 3 - Continued

	Willow	Populus	Dandelion	Honey Suckle	Rose	Alsike Clover	Sweet Clover	Rape	Raspberry	Fireweed
<u>Osmia</u> sp				X						
Colletidae										
Unidentified Andrenidae	X								X	
<u>Anthophora furcata terminalis</u> Cr.			X		X					
<u>Andrena catalinica</u> Cockerell	X									
<u>A. algida</u> Sm							X			
<u>A. commoda</u> Sm						X				
<u>A. bradleyi</u> Vier	X									
<u>A. vicinia</u> Sm					X					
<u>A. candida</u> Sm	X	X								
<u>Bombus affinus</u> Cr							X			
<u>B. rufocinctus</u> Cr	X				X		X			
<u>B. polaris</u> Frank						X	X	X		
<u>B. kirbyellis</u> Frank				X						
<u>B. vagans vagans</u> Sm					X	X			X	X
<u>B. occidentalis</u> <u>negroscutatus</u> Greene				X		X				
<u>B. terricola</u> Kby					X		X			
Coleptera										
Curculionidae		X								
Orsodacninae					X					

POLLEN PREFERENCES OF BEES

Levin and Bohart (1955) concluded that the odour of the pollen is an important factor in the selection of pollen by bees. To test whether certain pollen preferences of bees were caused by odour alone, an experiment was designed in which bees were exposed to the wind borne odour of pollen and their responses noted.

The experiments were based on the assumption that insects will move upwind when exposed to an air current bearing an attractive odour. Originally an apparatus designed by Hocking and Lindsay (1958, Figure 2) was used. It consisted of a T-tube across the top of which a current of air bearing the odour of pollen passed. The bees were introduced into the stem of the T-tube. Because the size limited the number of bees that could be introduced into the system and appeared to inhibit normal responses, the apparatus was considered unsatisfactory for my experiment. Therefore a wind tunnel based on a design by Carroll Smith (pers comm.) for mosquito studies was used for the experiment.

THE WIND TUNNEL

The base and side pieces were of plywood, with dimensions as follows: Length 152.0 cm, inside height 24.0 cm, width 23.0 cm. There was a narrow groove down the center of the base and two similar grooves 0.5 cm and 1.75 cm respectively from the top of the side pieces. The length of the tunnel was divided into three equal compartments by two lucite partitions. End pieces were made from a plywood frame 21.5 cm by 22.5 cm covered with wire mesh. These could be moved to any position in the tunnel by sliding along the grooves. The top of the tunnel was covered by three equal pieces of glass and the inside was painted white. The illumination in the tunnel was balanced by adjusting its position in the room and measuring the reflected light in either direction with a light meter.

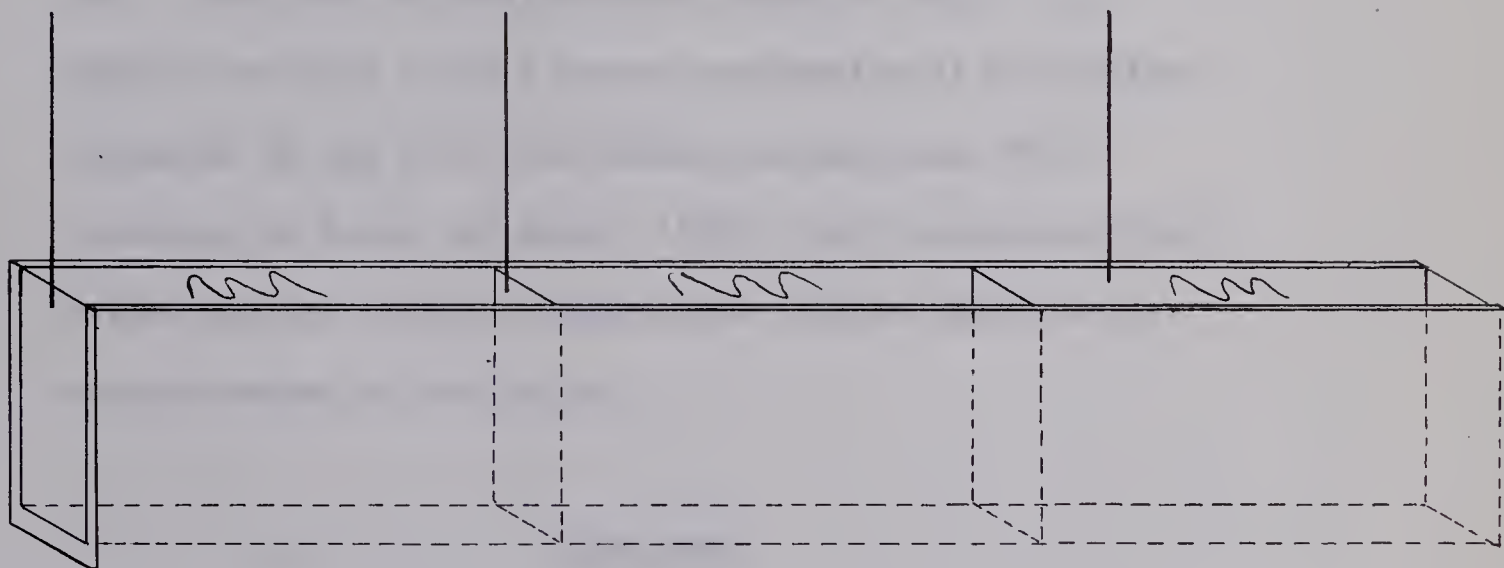
A pollen container 19.3 cm sq and 1.0 cm in thickness was made from fine brass screening and brass strips. This device was open at one side and when filled contained approximately 100 gm of pollen pellets. It fitted into either of the end pieces of the tunnel. (Figure 8)

An 8 inch .75 amp 115 V fan was used to blow air through the pollen and thence its odour along the tunnel at a speed of 76 meters per minute (approximately 3 mph).

Sliding end pieces
fit in tunnel

Lucite partition

Glass top



Scale 1 cm = 10 cm

Figure 8: The Wind Tunnel

THE POLLEN

Pollen collected in the pollen traps was sorted to plant species by colour and then stored in polythene bags. Six different pollens were used. The rape, plum, and willow pollen were collected in the summer of 1966, the dandelion in the summer of 1965, and the sweet clover pollen was obtained from Beaverlodge, Northern Alberta in 1965. The last two pollens were stored at -10°C . A mixture was made up of a random combination of the pollens collected by the bees from mid-May to mid-June 1966. According to Levin and Bohart (1955), the freshness of the pollen and its moisture content have little effect on the attractiveness of the pollen.

THE BEES

For the experiments an observation hive was maintained in the laboratory. The hive contained four frames and was stocked by a swarm obtained from one of the extra colonies maintained on Parkland Farm during June 1966. The colony was healthy and brood was being reared.

EXPERIMENTAL PROCEDURE

Approximately 100 bees were removed from the hive and placed in the central section of the wind tunnel. The end pieces were pushed to the lucite partitions. The lucite partitions were raised and air blown over the bees by the fan for 5 minutes. The lucite partitions were replaced and the end pieces moved back to their original positions.

The pollen container with pollen was placed in an end piece, the fan restarted and the lucite partitions removed again for 2 minutes. The lucite partitions were then dropped into position and the numbers of bees in each section were counted. The bees were pushed back to the central portion by moving the end pieces inwards. The lucite partitions were removed and clean air was blown through the tunnel, over the bees for five minutes to remove all traces of odour. The test was repeated from the opposite end of the tunnel to avoid positional conditioning of the bees. Twelve tests were carried out for each kind of pollen.

Controls were run using the empty clean pollen container. The tests with pollens were interrupted at random with a control to check that the bees were behaving in a normal manner.

Each batch of bees was used for an average of six tests. The bees were not fed during the trials and were not returned to the hive after testing.

RESULTS AND DISCUSSION

The Behaviour of the Bees in the Tunnel.

Very few bees responded by flying towards the source of the stimulus. The majority crawled. In all tests a number of bees remained stationary, facing the source of the stimulus, raising their abdomens and fanning with their wings. If the bees remained in the tunnel longer than the time taken for seven tests - a period of about 50 minutes, they began to solicit food from each other and gather in clusters. A number showed signs of lack of food.

The Response to Different Pollens.

See appendices for raw data and statistics.

TABLE 4

The Distribution Of Bees In The Wind Tunnel After Being Exposed To
The Wind Borne Odour Of Various Pollens

Pollen	No. Of Bees Used In Experiment	% Bees Upwind	% Bees In Central Portion	% Bees Downwind
Control	954	34.6	43.1	22.3
Mixed	831	58.2	29.4	12.4
Rape	909	53.1	34.3	12.6
Sweet Clover	1329	50.2	37.8	12.0
Plum	1352	51.2	37.1	11.7
Dandelion	1109	54.4	28.9	16.7
Willow	1224	50.5	38.1	11.4

A number of statistical tests were carried out on the data to establish whether the responses of the bees to the control conditions and to the various pollens were significantly different, and to form a list of pollen preferences in sequence.

A X^2 test of the ratio of the bees upwind and downwind in the control and the ratios of the distribution of the bees for each pollen established that the control was significantly different from all the pollens. An index of attraction for the pollens and the control to give an indication of the relative attractiveness of the pollens was also calculated for each run, and averaged for each pollen.

$$\text{Index of attraction} = \left(\frac{\text{number of bees upwind} - \text{number of bees downwind}}{\text{number of bees upwind} + \text{number of bees downwind}} \right) \times 100$$

The results are as follows: Mixed pollen 64; Rape pollen 63; Sweet Clover 57; Plum 54; Dandelion 46; Willow 31; Control 10.

As the X^2 test does not take into account variation within samples an analysis of variance was carried out on the raw data to see whether the differences in response between the different pollens and the control were significant. None of them quite reached the level for significance at the 5% probability level. A Duncan's Multiple Range Test on the means was carried out. Again no significant differences ($P = 0.05$) between the means were obtained.

Thus the phenomenon of pollen preferences using odour alone as the attractant was not established.

CONCLUSIONS

From this work some general conclusions may be drawn about bee-pollen relationships in this area. Perhaps the most important is that, whereas Todd and Bishop (1940), working in California, state that the seasonal trends in the quantity of pollen collected by a colony of bees are in rhythm with the flowering of the main pollen sources, colony condition having little effect on the phenomenon, my results showed that colony condition had an effect on the amounts of pollen brought into the hive. This may be explained by comparing the growing season in California with that in Northern Alberta. Here the season is considerably shorter than in California. As a result abundant pollen supplies are available throughout the season, whereas in California dearth periods occur. Thus the colony condition in Alberta is the most important factor governing the amount of pollen collected by a colony. Day to day variation is associated with the weather.

A study of the range of plant species from which pollen was collected led to the conclusion that availability and abundance are the prime factors governing which pollens will be collected by bees.

The relationships between pollen pellet size and the constituent pollen grains should be further studied. The number of pollen grains per pellet could be counted and the food value of the pellet assayed. It may then be possible to make recommendations as to pollen plants offering the most nutrients per unit energy spent on collection.

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APPENDIX 1

GROSS VOLUMES OF POLLEN REMOVED FROM TRAPS

1965			1966	
Sampling Date	1965A	1965B	Sampling Date	1966A
4 May	30 ml	174 ml		
8 May	-	310 ml		
12 May	264 ml	390 ml		
16 May	66 ml	142 ml		
20 May	-	-		
24 May	102 ml	450 ml	24 May	150 ml
28 May	90 ml	280 ml	27 May	570 ml
1 June	56 ml	240 ml	31 May	250 ml
5 June	520 ml	-	8 June	550 ml
9 June	230 ml	426 ml	12 June	350 ml
13 June	310 ml	275 ml	16 June	200 ml
17 June	784 ml	380 ml	20 June	150 ml
20 June	210 ml	32 ml	24 June	40 ml
25 June	768 ml	110 ml	28 June	170 ml
30 June	-	-	2 July	98 ml
4 July	1080 ml	120 ml	6 July	140 ml
8 July	315 ml	40 ml	10 July	140 ml
12 July	800 ml	42 ml	14 July	130 ml
16 July	586 ml	30 ml		
20 July	258 ml	54 ml		
24 July	-	70 ml	26 July	250 ml
1 Aug	-	-	3 Aug	520 ml
5 Aug	343 ml	-	8 Aug	185 ml
8 Aug	640 ml	140 ml	20 Aug	550 ml
13 Aug	500 ml	180 ml		
17 Aug	160 ml	90 ml		
21 Aug	670 ml	330 ml		
25 Aug	594 ml	496 ml		
2 Sept	160 ml	340 ml		
6 Sept	12 ml	10 ml		

APPENDIX 2

RAW WIND TUNNEL DATA

Pollen	Test No.	Number of Bees Upwind Pollen	Number of Bees Not Responding To Pollen	Number of Bees Downwind Pollen
Mixed	1	29	32	11
	2	37	28	6
	3	33	6	10
	4	18	9	22
	5	16	78	2
	6	57	6	2
	7	45	9	2
	8	34	12	3
	9	55	10	15
	10	55	15	14
	11	53	20	7
	12	52	19	9
Plum	1	20	67	25
	2	94	10	8
	3	41	56	16
	4	56	41	13
	5	50	27	25
	6	35	47	12
	7	15	100	12
	8	36	70	17
	9	82	29	9
	10	81	27	11

Appendix 2 - Continued

Pollen	Test No.	Number of Bees Upwind Pollen	Number of Bees Not Responding To Pollen	Number of Bees Downwind Pollen
Plum	11	100	9	9
	12	82	18	2
Sweet Clover	1	33	64	2
	2	33	51	12
	3	38	41	17
	4	47	43	6
	5	26	26	32
	6	56	32	18
	7	51	50	32
	8	65	54	6
	9	102	17	6
	10	87	28	8
	11	24	81	18
	12	105	16	2
Willow	1	83	15	0
	2	90	5	4
	3	57	26	12
	4	8	134	10
	5	117	35	0
	6	112	30	10
	7	86	41	19
	8	8	49	11
	9	37	21	9

Appendix 2 - Continued

Pollen	Test No.	Number of Bees Upwind Pollen	Number of Bees Not Responding To Pollen	Number of Bees Downwind Pollen
Willow	10	8	19	38
	11	2	55	8
	12	10	36	19
Rape	1	14	65	1
	2	15	43	22
	3	63	17	1
	4	52	22	3
	5	34	32	7
	6	44	20	9
	7	42	24	6
	8	56	11	5
	9	65	3	1
	10	35	16	13
	11	46	35	3
	12	17	24	43
Dandelion	1	71	6	2
	2	38	20	20
	3	39	22	3
	4	16	58	24
	5	78	18	10
	6	62	12	20
	7	55	25	14
	8	19	32	39
	9	21	71	12

Appendix 2 - Continued

Pollen	Test No.	Number of Bees Upwind Pollen	Number of Bees Not Responding To Pollen	Number of Bees Downwind Pollen
Dandelion	10	29	42	33
	11	89	11	2
	12	86	4	6
Control	1	14	30	11
	2	19	22	11
	3	13	29	10
	4	4	24	20
	5	11	21	18
	6	17	64	20
	7	28	46	27
	8	15	46	40
	9	78	17	1
	10	33	47	20
	11	25	54	20
	12	73	11	15

APPENDIX 3

STATISTICAL TREATMENT OF WIND TUNNEL DATA

In all cases only the number of bees upwind and number of bees downwind the pollen odour source were considered. The values for the analysis of variance were calculated as follows.
$$\frac{\text{number upwind}}{\text{number upwind} + \text{number downwind}} \times 100$$

ANALYSIS OF VARIANCE

Treatments

Runs	Control	Mixed	Rape	S.Clover	Plum	Dandelion	Willow	
1	56	73	93	94	44	97	100	
2	63	86	41	73	92	66	96	
3	57	77	98	69	72	93	83	
4	17	45	95	89	81	40	44	
5	38	89	83	45	67	89	100	
6	46	97	83	76	74	76	93	
7	51	96	88	61	56	80	82	
8	27	92	92	92	68	33	42	
9	99	79	98	94	90	64	80	
10	62	80	73	92	88	47	17	
11	56	88	94	57	92	98	20	
12	83	85	28	98	98	93	34	
ANGULAR TRANSFORMATION								
1	48.45	58.69	74.66	75.82	41.55	80.03	88.19	
2	52.54	68.03	39.82	58.69	73.57	54.33	78.46	
3	49.02	61.34	81.87	56.17	58.05	74.66	65.65	
4	24.35	42.13	77.08	70.63	64.16	39.23	41.55	
5	38.06	70.63	65.65	42.13	54.94	70.63	88.19	
6	42.71	80.03	65.65	60.67	59.34	60.67	73.57	
7	45.57	78.46	69.73	51.35	48.45	63.43	64.90	
8	31.31	73.57	73.57	73.57	55.55	35.06	40.40	
9	84.26	62.73	81.87	75.82	71.57	53.13	63.43	
10	51.94	63.43	58.69	73.57	69.73	43.28	24.35	
11	48.45	69.73	75.82	49.02	73.57	81.87	26.57	S.T.
12	65.65	67.21	31.95	81.87	81.87	74.66	35.67	5118.21
	582.31	795.98	796.36	769.31	752.35	730.98	690.92	

Appendix 3 - continued

$\bar{X}$ 48.53 66.33 66.36 64.12 62.69 60.92 57.67

$$\text{Correction Factor} = \frac{(5118.21)^2}{84} = 311858.8$$

Total S.S.	333646.0	Treatment S.S.	314702.4
-	<u>311858.8</u>	-	<u>311858.8</u>
	21787.2		2843.6

Source of Variation	DF	SS	MS	F
Treatments	6	2843.6	473.9	1.9
Error	77	18943.6	246.0	
Total	83	21787.2		

F is Non significant at 5% level

Duncans Multiple Range Test

Control	Salix	Dandelion	Plum	S. Clover	Mixed	Rape
48.53	57.67	60.92	62.69	64.12	66.33	66.36

$$\text{Standard error of the mean } \bar{S\bar{X}} \frac{E(ms)}{r} = \frac{246.0}{12} = 4.53$$

(SEm)

No. of means P:	2	3	4	5	6	7
Significant studentized ranges P = 5%	2.815	2.965	3.065	3.13	3.19	3.23
SEm x SSR=LSR	12.8	13.4	13.9	14.2	14.5	14.6

$$\text{Rape} - (\text{LSR})_{p_7} \quad 66.36 - 14.6 = 51.76$$

. . . Rape, mixed, sweet clover, plum, dandelion, salix form a sub-set.

$$\text{Dandelion} - (\text{LSR})_{p_3} \quad 60.92 - 13.4 = 47.52$$

. . . Dandelion, salix and control form a sub-set.

. . . No significant difference at P = 5% is found between the means.



B29875